Space Technology Research Grants

Investigation of Transient Plasma Processes and Anamlous Electron Transport in Hall Effect Thrusters

Completed Technology Project (2011 - 2015)

Project Introduction

High-power electric propulsion (EP) systems are an innovative space technology that have the potential to significantly expand NASA's capability for robotic and human exploration of the solar system. Their highly efficient use of propellant mass (high specific impulse) greatly reduces the total mass of propellant required to complete a given mission. Common EP systems such as Hall thrusters and ion engines produce low thrust resulting in impractically long trip times for human missions. To enable ambitious planetary exploration missions high specific impulse and high-thrust systems are needed; for example clustered Hall thrusters, concentric nested Hall thrusters or the Variable Specific Impulse Magnetoplasma Rocket (VASIMR). A new propulsion system has been proposed using a Field Reverse Configuration (FRC) plasma source called the Electrodeless Lorentz Force (ELF) thruster. Preliminary studies have shown that the ELF has excellent specific impulse and thrust throttling similar to other high-power EP systems with the advantages of higher thrust density, higher efficiency and a smaller footprint. An FRC plasma source produces high-density, magnetized plasmoids (self-contained bodies of plasma) that are disconnected from externally applied magnetic fields. FRC plasma sources are inherently pulsed devices where the plasmoid evolves in three steps 1) Neutral gas injection and ionization 2) Plasmoid growth and acceleration and 3) Plasmoid ejection. The ELF thruster is a unique FRC plasma source that uses a Rotating Magnetic Field (RMF) to drive the azimuthal current creating the reversed magnetic field. FRC plasma sources were originally developed for nuclear fusion applications and required significant user intervention during operation. The ELF thruster has only operated in single pulse mode for basic characterization but will likely need to complete billions of pulses in an actual mission scenario. To successfully transition the ELF or other FRC thrusters from a few pulses into billions of pulses for space mission applications, the transient processes of energy deposition into the plasma, magnetic field reversal during FRC onset, the plasmoid structure, and plasmoid instabilities need to be fully understood. This proposed research will use the ELF thruster to study the transient processes of plasmoid formation, structure and instabilities to make FRC thrusters viable propulsion systems. The research will be conducted in the Plasmadynamics and Electric Propulsion Laboratory (PEPL) at the University of Michigan under Professor Alec Gallimore. The advanced diagnostics in development at PEPL including the High-speed Dual Langmuir Probe (HDLP) coupled with an ultra-fast camera (FastCam) and time resolved LASER Induced Fluorescence (LIF) have enabled unprecedented measurements of transient plasmas. The HDLP operating at 100 kHz and the FastCam operating at 109,500 fps produced pioneering spatial and temporal views of Hall thruster plasma plume properties. A faster HDLP under development will enable the 1 MHz data acquisition rate necessary to capture an FRC plasmoid that is formed and ejected in approximately 20 micro-seconds. Using these tools the number density, electron temperature, plasma potential and ion velocity distributions will be mapped in and around the ELF thruster during the life cycle of each

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Table of Contents

Organizational Responsibility

Responsible Mission Directorate:

Space Technology Mission Directorate (STMD)

Responsible Program:

Space Technology Research Grants

pulse. These data will yield tremendous insight into the plasma structure and evolution in an FRC thruster and help answer questions regarding plasmoid shape and size, the effect of plasma instabilities on reliability and efficiency, and the existence of residual plasma between pulses. The research will be conducted in four phases 1) Literature review and theory development 2) Install, operate and characterize an ELF thruster in PEPL 3) Acquire plasma data with the HDLP, FastCam and time-resolved LIF and 4) Data analysis to improve FRC design for spacecraft applications to minimize energy loss and increase stability.

Anticipated Benefits

High-power electric propulsion (EP) systems are an innovative space technology that have the potential to significantly expand NASA's capability for robotic and human exploration of the solar system. Their highly efficient use of propellant mass (high specific impulse) greatly reduces the total mass of propellant required to complete a given mission. Common EP systems such as Hall thrusters and ion engines produce low thrust resulting in impractically long trip times for human missions. To enable ambitious planetary exploration missions high specific impulse and high-thrust systems are needed; for example clustered Hall thrusters, concentric nested Hall thrusters or the Variable Specific Impulse Magnetoplasma Rocket (VASIMR). A new propulsion system has been proposed using a Field Reverse Configuration (FRC) plasma source called the Electrodeless Lorentz Force (ELF) thruster. This project uses the ELF thruster to study the transient processes of plasmoid formation, structure and instabilities to make FRC thrusters viable propulsion systems. The resulting data will yield tremendous insight into the plasma structure and evolution in an FRC thruster and help answer questions regarding plasmoid shape and size, the effect of plasma instabilities on reliability and efficiency, and the existence of residual plasma between pulses.

Project Management

Program Director:

Claudia M Meyer

Program Manager:

Hung D Nguyen

Principal Investigator:

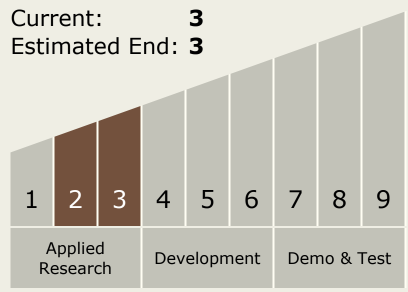
Alec Gallimore

Co-Investigator:

Michael J Sekerak

Technology Maturity (TRL)

Start: **2**
Current: **3**
Estimated End: **3**

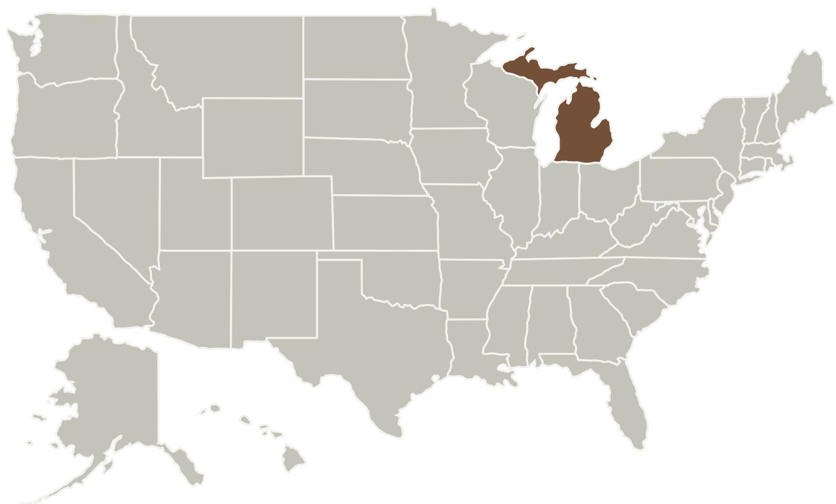


Technology Areas

Primary:

- TX01 Propulsion Systems
  └ TX01.2 Electric Space Propulsion
    └ TX01.2.2 Electrostatic

Primary U.S. Work Locations and Key Partners



Organizations Performing Work	Role	Type	Location
University of Michigan-Ann Arbor	Supporting Organization	Academia	Ann Arbor, Michigan

Primary U.S. Work Locations
Michigan

Project Website:

https://www.nasa.gov/directorates/spacetech/home/index.html